III. "On the Pressure of Wind on Curved Vanes." By W. H. Dines, B.A. Communicated by the Meteorological Council. Received May 14, 1891.

In June, 1890, a paper* was presented to the Royal Society showing the results of some experiments upon wind pressure upon an inclined surface, and I now give an account of some supplementary work upon the same subject which has been done during the past winter.

The apparatus was the same as that previously described, with the exception of the actual pressure plate, and precisely the same method of observation has been adopted.

Instead of a flat wooden plate, a piece of sheet metal 1 foot square has been used, the metal being bent so as to form a portion of a cylinder, the curvature of which was easily varied by drawing the opposite edges more or less together by means of two fine wires. The plate was attached to the lever of the apparatus by about 13 in. of 1-in. brass tube, the tube passing a little more than half way across the back of the plate. It is evident that the tube must interfere with the free passage of the air over the back of the plate, but some kind of support behind cannot be avoided.

In certain positions, experiments could not be made on account of the unsteadiness of the motion, and the consequent fluttering of the sheet metal. There was no trouble in getting the value of the pressure in these positions, but the vibratory motion was often so violent that it tore the metal, almost as though it were paper, and soon rendered the plate useless. These positions are all marked * in the tables; and the corresponding values are more or less uncertain, because, as soon as the vibrations were apparent, the engine was stopped as quickly as possible to avoid the trouble of having to obtain a new plate.

As in the preceding paper, 100 has been taken to represent the moment of the pressure upon one sq. ft. exposed normally at 1 ft. from the axis, and all other moments are expressed relatively to this.

The results obtained are given in the following tables, the diagram at the head of each table showing the form of surface to which it applies. No attempt has been made to eliminate the effect of the eddy from the frame of the apparatus, a full discussion of which will be found in the paper referred to. The values given also include the pressure upon the supporting arm. This is counterbalanced in the normal position, but must have an increasing effect as the angle of incidence increases, and for this reason it has been considered useless to carry the experiments much beyond an angle of 60° or 70°.

* 'Roy. Soc. Proc.,' vol. 48, p. 233.

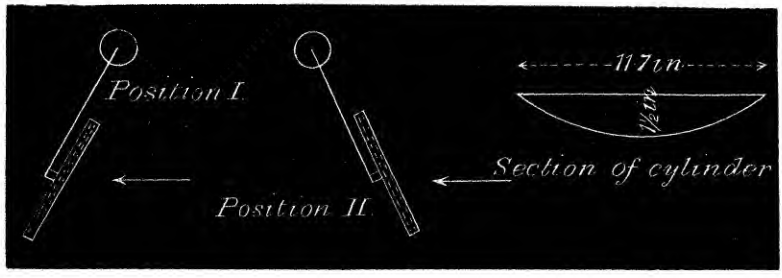
The diagrams showing the way in which the normal component of the pressure varies with the angle of incidence have been obtained by taking the mean values from positions I and II. In drawing the curves, the want of observations at the intermediate angles was felt, but I do not think that further experiments would greatly modify the forms obtained.

A few observations with the plate in the other position, *i.e.*, with the axis of the cylinder parallel to the long arm of the whirling machine, have been made. They are given in Tables IV and V.

In Tables I, II, IV, and V the results have been reduced to pressures per sq. ft.; this has been done by multiplying by 12/11·7 and 12/9 respectively. In Table III, the rectangle contained by the two straight edges and the chords of the curved edges contains 1 sq. ft. (the length being 28·8 in.); hence in this case no reduction is necessary.

Table I.—Axis of Cylinder inclined to the Wind.

Fig. 1.



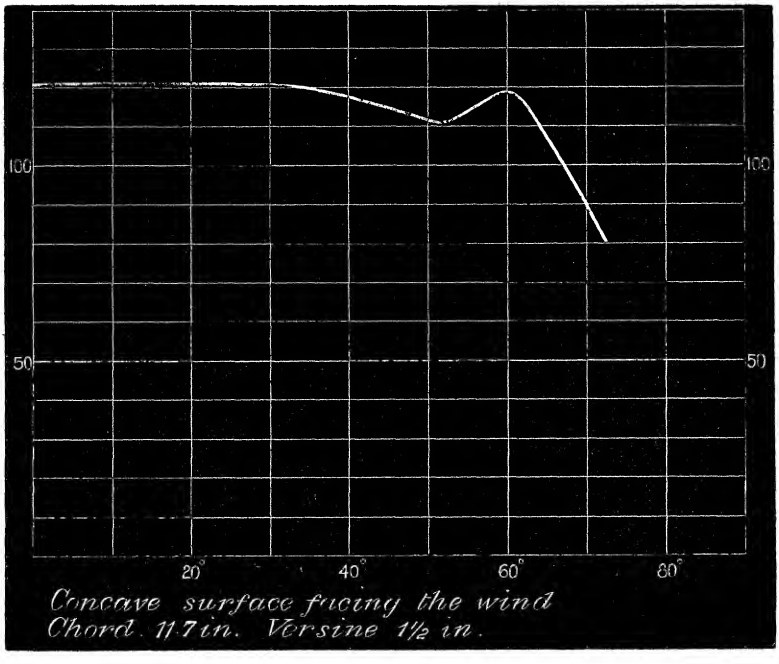
Concave surface facing the wind.

Position I.		Position II.	
Angle of incidence.	Value of moment.	Angle of incidence.	Value of moment.
0°	135, 121, 116, 117		
20	113, 118	20°	136, 131, 120, 117
40	108	30	129, 121, 107, 114, 110
45	111	40	128, 130
50	107, 109	45	135, 131, 113, 113
60	108	50	139, 120, 113, 123, 108
*70	*89	55	138, 125, 127
*80	*59	60	126, 130, 134, 138
		70	96, 100, 96, 98

Convex surface facing the wind.

0	87, 77, 76		
20	78, 82, 86	20	72, 73, 82, 87
40	73, 75, 71, 71	40	63, 64
50	69, 67, 65	45	78
60	62, 65, 59	50	65
70	*74, *71	60	63, 55
		70	56, 58, 60

Normal Component. From Table I.



Normal Component. From Table I.

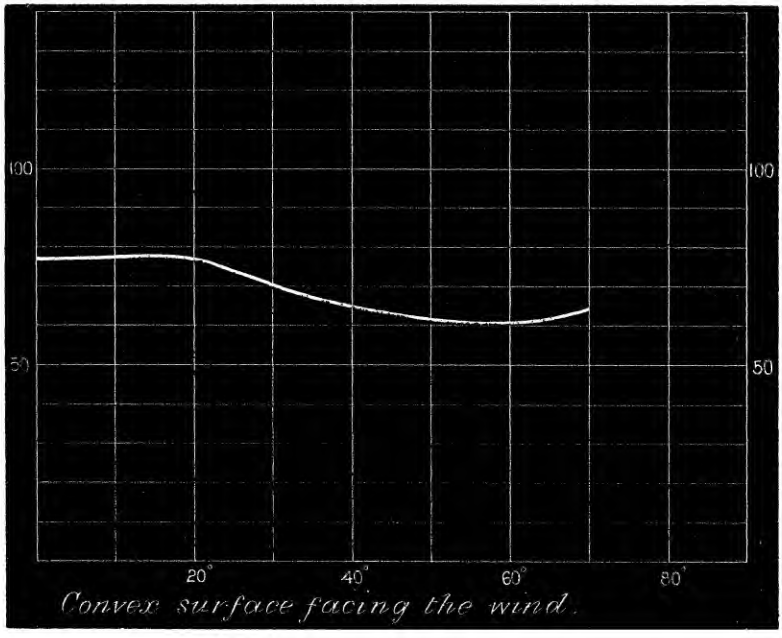


Table II.—Axis of Cylinder inclined to the Wind.

Fig. 2.

Section of cylinder.

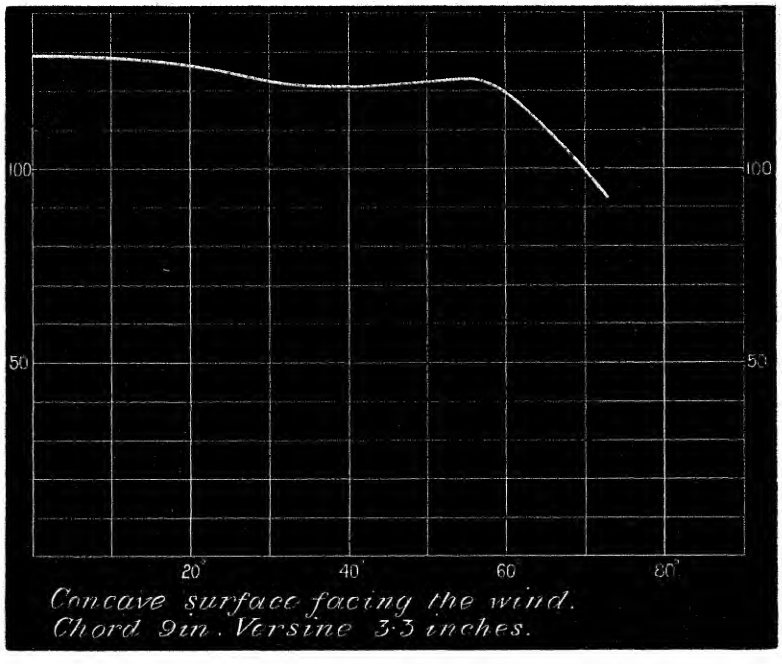
Concave surface facing the wind.

Position I.		Position II.	
Angle of incidence.	Value of moment.	Angle of incidence.	Value of moment.
0°	127, 129, 133, 125		
20	124, 136	20°	121, 133, 122, 127
40	121, 139	40	120, 116
50	120, 137	50	121, 119, 116
55	*125	55	116
60	*105, *99	60	112, 100

Convex surface facing the wind.

0	60, 63, 65, 68		
20	60, 64	20	60
40	63, 68, 69	40	52, 58
50	61, 64, 75, 73	50	52, 56
60	67, 69, 72, 72	60	47, 53, *56
70	*57, *53	70	*48

Normal Component. From Table II.



Normal Component. From Table II.

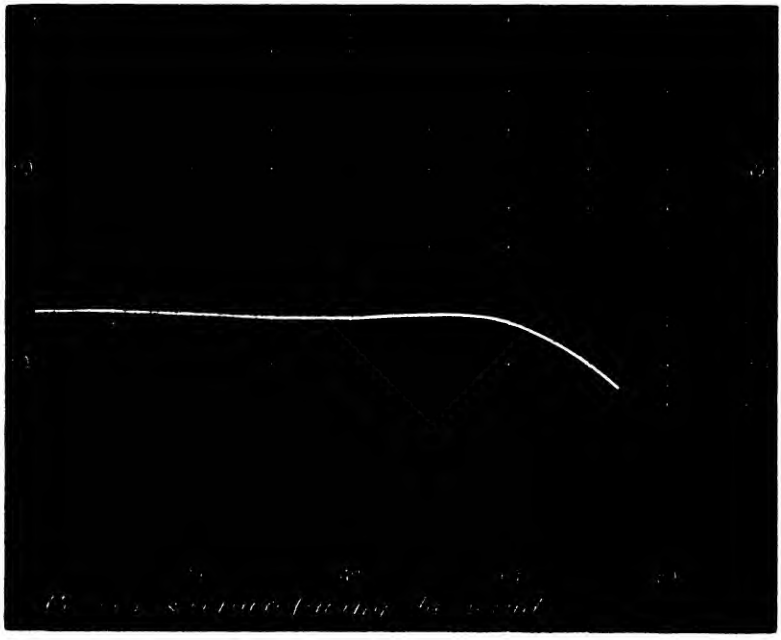


Table III.—Axis of Cylinder inclined to the Wind.

Length of plate, 28·8 in., so that the area of projection of plate might be 1 sq. ft.

Fig. 3.

Section of cylinder.

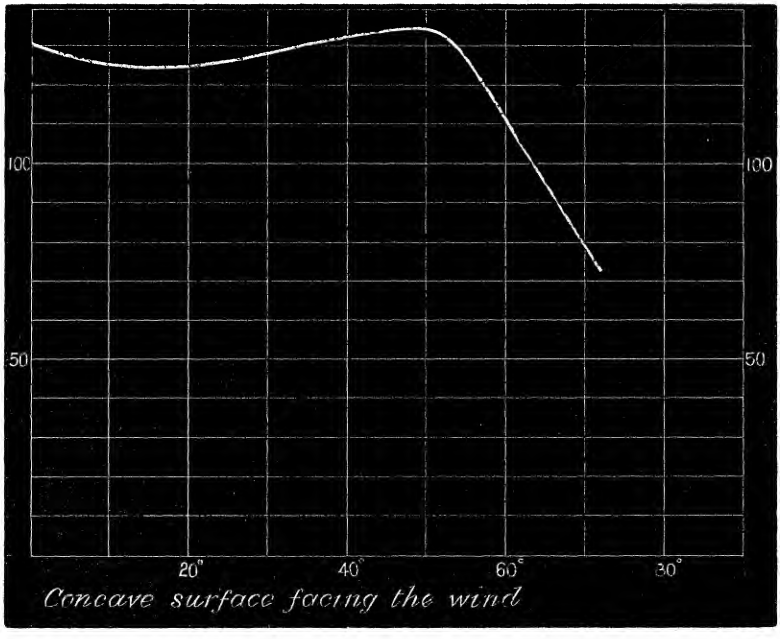
Concave surface facing the wind.

Position I.		Position II.	
Angle of incidence.	Value of moment.	Angle of incidence.	Value of moment.
0°	133, 125		
20	108	20° ..	143, 141, 145, 147
40	101, 103, 105, 105, 106	30 ..	144
50	*90, *87, 83, 88	40 ..	151, 165, *143, *165, 168
60	71, 73	45 ..	*167
70	57	50 ..	*175, 181, 187
		55 ..	*171
		60 ..	143, 148, 152, 157
		70 ..	99, 105

Convex surface facing the wind.

0	.... 89, 87, 96, 90	20	 102
20	.... 89, 94, 96	40	.... 119, 114, 124
40	.... 67, 71	50	.... 131, 130, 145
50	 54	60	.... 113, 118
60	 42	70	 78
70	.... 28, 29		
80	 15		

Normal Component. From Table III.



Normal Component. From Table III.

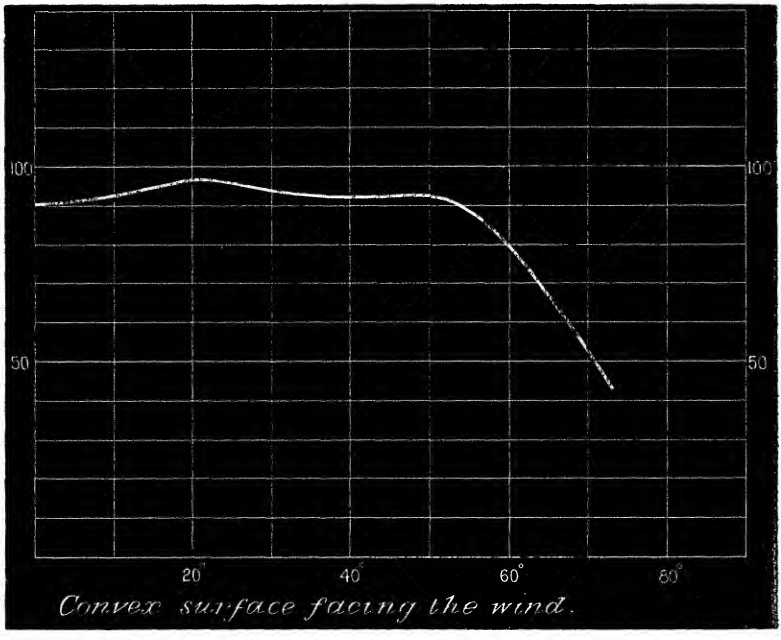
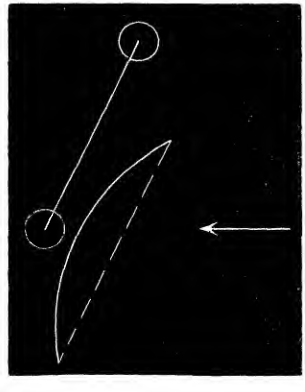


Table IV.—Chord of Cylinder inclined to Wind Direction.

Same plate as Table I. Chord 11·7 in.

Fig. 4.



Concave surface facing the wind.

Position I.		Position II.	
Angle of incidence.	Value of moment.	Angle of incidence.	Value of moment.
0°	111, 116		
$22\frac{1}{2}$	116	$22\frac{1}{2}$°	118
45	*124, 130	45	117, *113

Convex surface facing the wind.

0	86		
$22\frac{1}{2}$	65	$22\frac{1}{2}$	76
45	43	45	46

Table V.—Chord of Cylinder inclined to the Wind.

Same plate as in Table II. Chord 9 in.

Concave surface facing the wind.

Position I.		Position II.	
Angle of incidence.	Value of moment.	Angle of incidence.	Value of moment.
0°	131		
20	*152	20°	120, 130
		40	134

Convex surface facing the wind.

0	64		
20	45, 46	20	56
40	24	40	24

Experiments for the purpose of finding how the curvature influences the resistance at perpendicular incidence have also been made.

The curvature of the plate was gradually increased by drawing the opposite edges more closely together, and the corresponding pressures were obtained, both with the concave and convex surfaces facing the wind.

The projection of the plate upon a plane perpendicular to the wind direction becomes less as the curvature increases, but the pressures have been reduced to unit area, so that they may be easily comparable. It should be noted, however, that the pressure upon a rectangle is less than upon an equal square, the difference being considerable if the rectangle be long and narrow.

The results are given in the following table :—

Table showing the Relation between Resistance and Curvature.

The negative sign placed before the versine means that the convex surface is facing the wind. In each case the area of the plate is 1 sq. ft.

Chord.	Versine.	Area of projection.	Relative pressure per sq. ft.
7·6 in.	−3·8 in.	0·633 sq. ft.	72
8·4 „	−3·6 „	0·70 „	72
9·0 „	−3·3 „	0·75 „	70
10·8 „	−2·1 „	0·90 „	80
11·6 „	−1·5 „	0·97 „	82
12·0 „	0 „	1·00 „	114
12·0 „	0·5 „	1·00 „	126
11·8 „	1·0 „	0·98 „	129
11·6 „	1·5 „	0·97 „	130
10·9 „	2·0 „	0·91 „	127
9·0 „	3·3 „	0·75 „	129

The values could not be obtained beyond this on account of the fluttering of the plate.

The following values are given here for the sake of comparison. They were obtained in May, 1889, by a similar method. The pressures are expressed per sq. ft. in the same scale :—

A 9-in. Robinson cup, concave	132
„ convex	45
A 5-in. Robinson cup, concave	126
„ convex	55
A plate 6 in. diameter, with cone angle 90° at back	112
The same with cone in front	74
A plate 6 in. diameter, with cone angle 30° at back	115
The same with cone in front	45

From these values the curve given below showing the relation between the pressure per unit area and the curvature has been constructed in a manner suggested by Professor Darwin. The ordinates give the resistance per unit area of projection of plate, and the abscissæ the angle subtended by a section of the plate at the centre of curvature.

There are one or two points in the curve which call for special notice.

The scale of pressure is the same as in the other tables and diagrams, and 100 in the scale represents a pressure of 1 lb. per sq. ft. at a velocity of $18\frac{1}{2}$ miles per hour. It was originally chosen so that 100 might denote the pressure upon a square plate of

1 sq. ft. area exposed normally, and hence the curve should intersect the middle line at a point where the ordinate is 100. It does not do so, however, partly on account of the eddy from the frame (see preceding paper), and partly because the two days on which the experiments relating to this curve were made both happened to be days on which the pressure was above the average.

The slight turning up of the line near the two ends may, perhaps, be due to the smaller area of projection and consequent increase of pressure per unit area in those positions, or it may be due to errors of observation. The curve was obtained from experiments upon one plate only, and it is not unlikely that a slightly different form might have resulted from the use of a larger or smaller square plate.

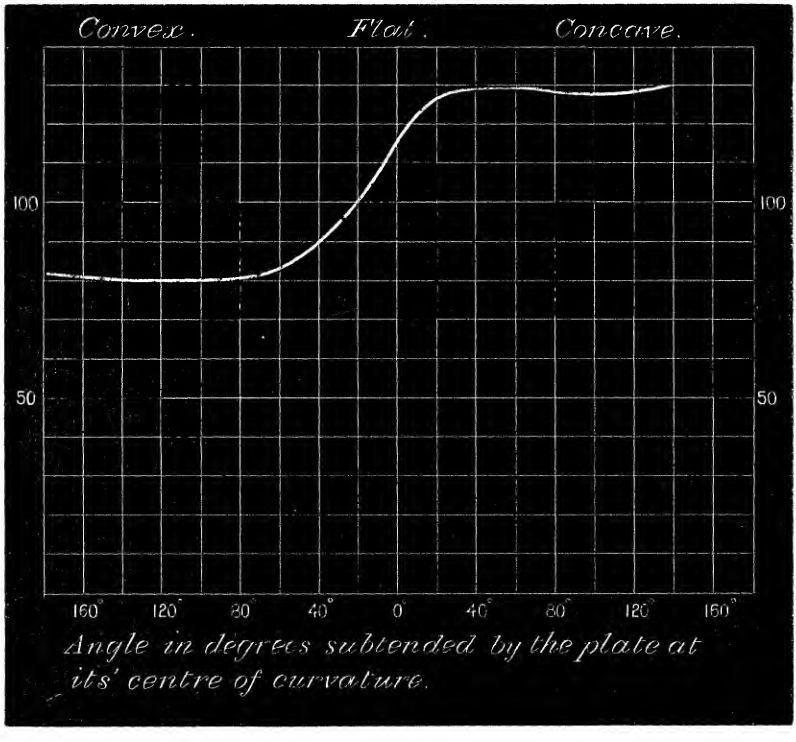
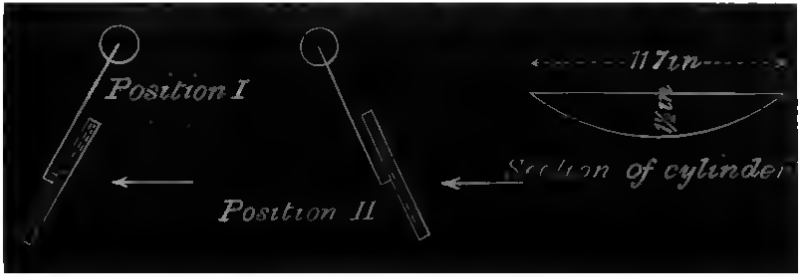


Diagram showing the Relation between the Resistance of a Curved Plate at Perpendicular Incidence per Unit Area of Projection and the Curvature.

Table I.—Axis of Cylinder inclined to the Wind.

Fig. 1.



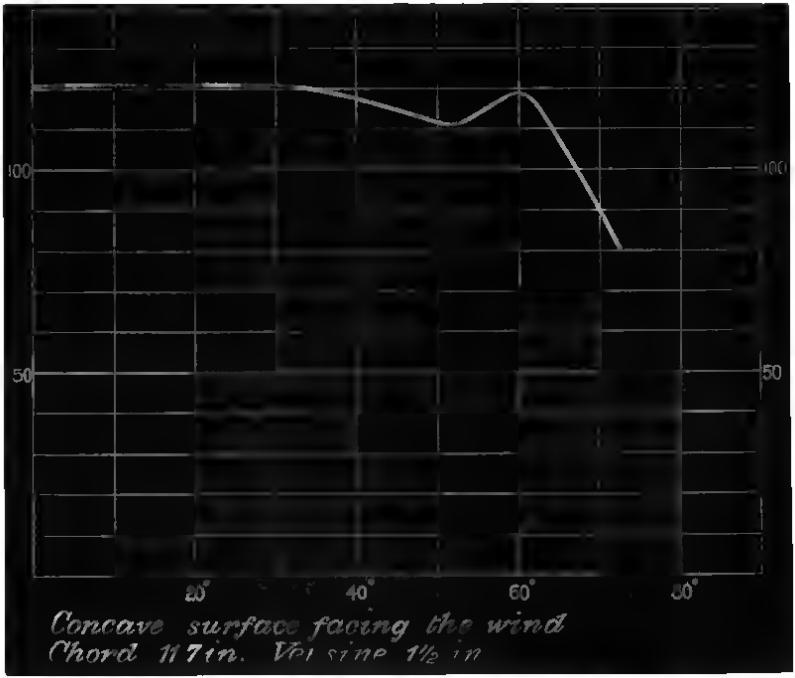
Concave surface facing the wind.

Position I.		Position II.	
Angle of incidence.	Value of moment.	Angle of incidence.	Value of moment.
0°	135, 121, 116, 117		
20	113, 118	20°	136, 131, 120, 117
40	108	30	129, 121, 107, 114, 110
45	111	40	128, 130
50	107, 109	45	135, 131, 113, 113
60	108	50	139, 120, 113, 123, 108
*70	*89	55	138, 125, 127
*80	*59	60	126, 130, 134, 138
		70	96, 100, 96, 98

Convex surface facing the wind.

0 ..... 87, 77, 76	
20 ..... 78, 82, 86	20 .... 72, 73, 82, 87
40 ..... 73, 75, 71, 71	40 .... 63, 64
50 ..... 69, 67, 65	45 78
60 ..... 62, 65, 59	50 65
70 .....*74, *71	60 .... 63, 55
	70 .... 56, 58, 60

Normal Component. **From Table I.**



Normal Component. From Table I.

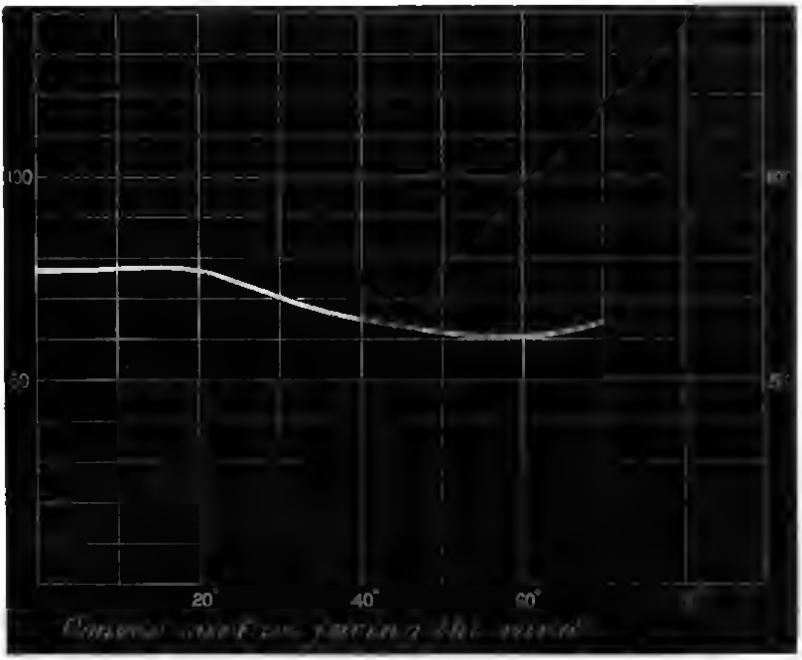


Table II.—Axis of Cylinder inclined to the Wind.

Fig. 2.

Section of cylinder.

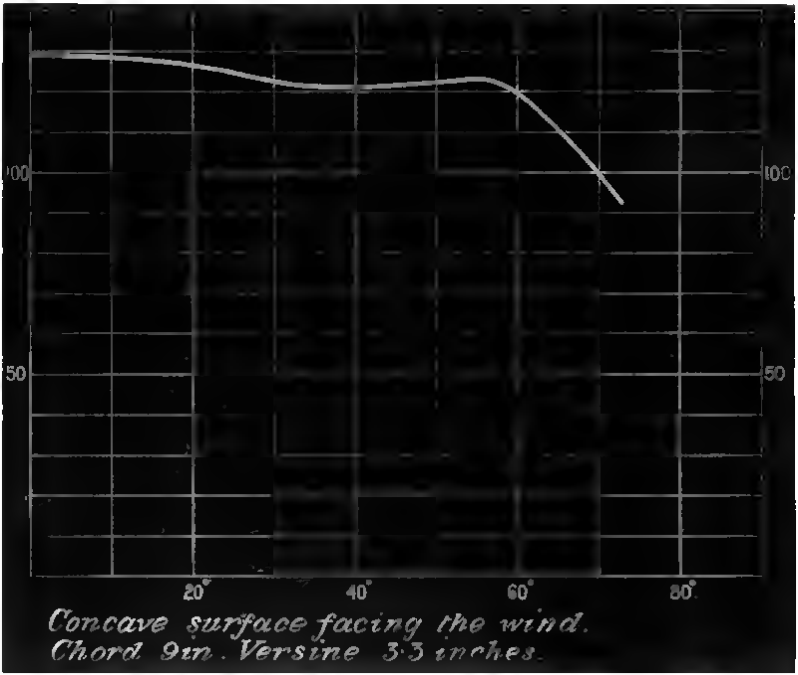
Concave surface facing the wind.

Position I.		Position II.	
Angle of incidence.	Value of moment.	Angle of incidence.	Value of moment.
0°	127, 129, 133, 125		
20	124, 136	20°	121, 133, 122, 127
40	121, 139	40	120, 116
50	120, 137	50	121, 119, 116
55	*125	55	116
60	*105, *99	60	112, 100

Convex surface facing the wind.

0 ..... 60, 63, 65, 68	
20 ..... 60, 64	20 60
40 ..... 63, 68, 69	40 ..... 52, 58
50 ..... 61, 64, 75, 73	50 ..... 52, 56
60 ..... 67, 69, 72, 72	60 ..... 47, 53, *56
70 .....*57, *53	70 .....*48

Normal Component. From Table II.



Normal Component. From Table II.

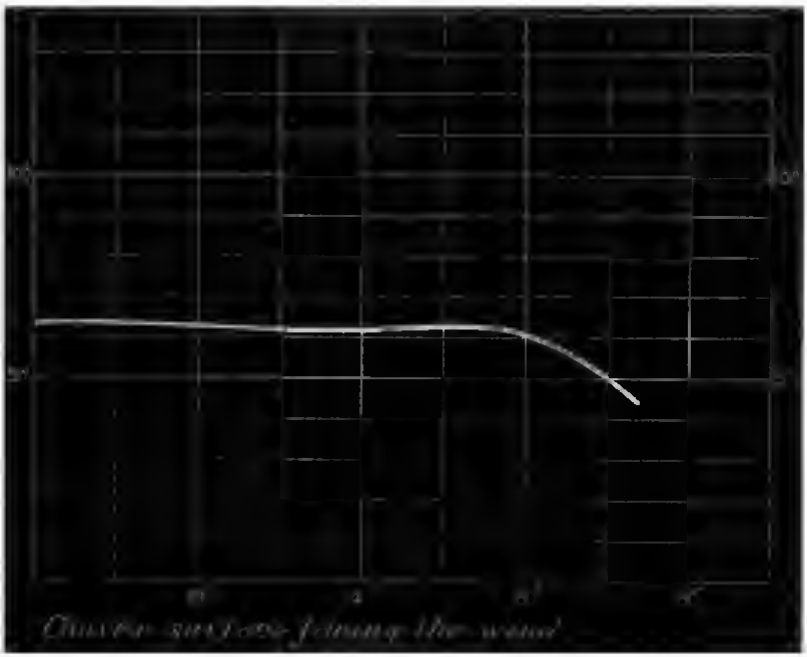


Table III.—Axis of Cylinder inclined to the Wind.

Length of plate, 28·8 in., so that the area of projection of plate might be 1 sq. ft.

Fig. 3.

Section of cylinder.

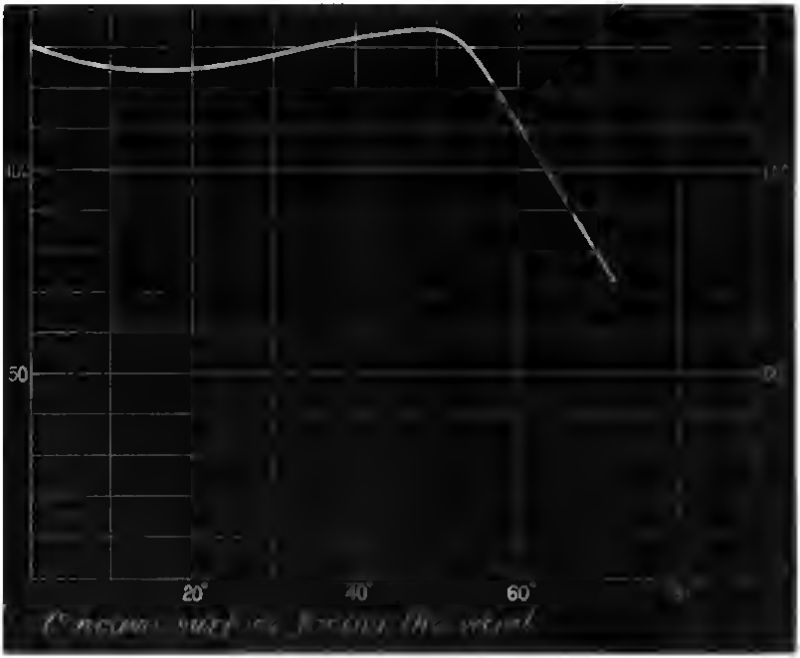
Concave surface facing the wind.

Position I.		Position II.	
Angle of incidence.	Value of moment.	Angle of incidence.	Value of moment.
0°	133, 125		
20	108	20° ..	143, 141, 145, 147
40	101, 103, 105, 105, 106	30 ..	144
50	*90, *87, 83, 88	40 ..	151, 165, *143, *165, 168
60	71, 73	45 ..	*167
70	57	50 ..	*175, 181, 187
		55 ..	*171
		60 ..	143, 148, 152, 157
		70 ..	99, 105

Convex surface facing the wind.

0	.... 89, 87, 96, 90		
20	.... 89, 94, 96	20	 102
40	.... 67, 71	40	.... 119, 114, 124
50	 54	50	.... 131, 130, 145
60	 42	60	.... 113, 118
80	 15	70	 78

Normal Component. From Table III.



Normal Component. From Table III.

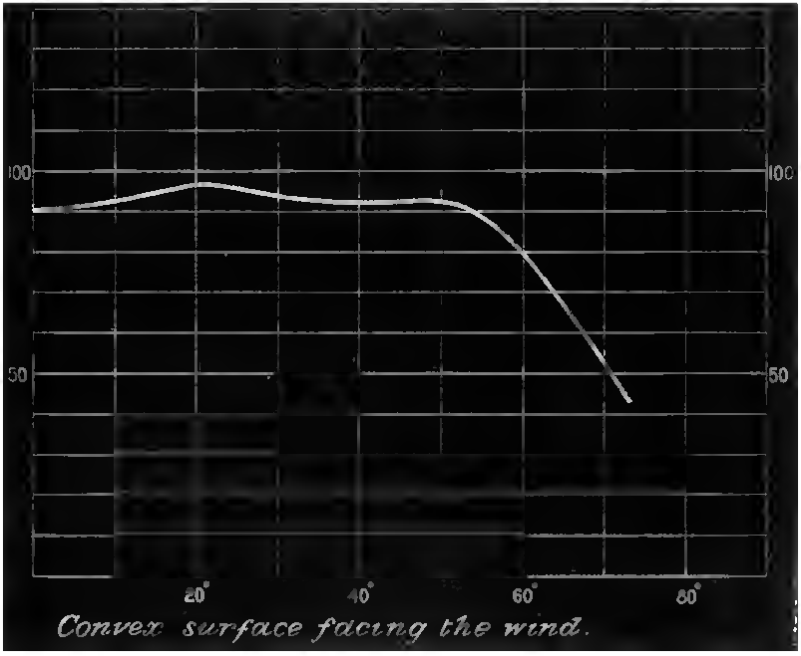


Table IV.—Chord of Cylinder inclined to Wind Direction.

Same plate as Table I. Chord 11·7 in.

Fig. 4.

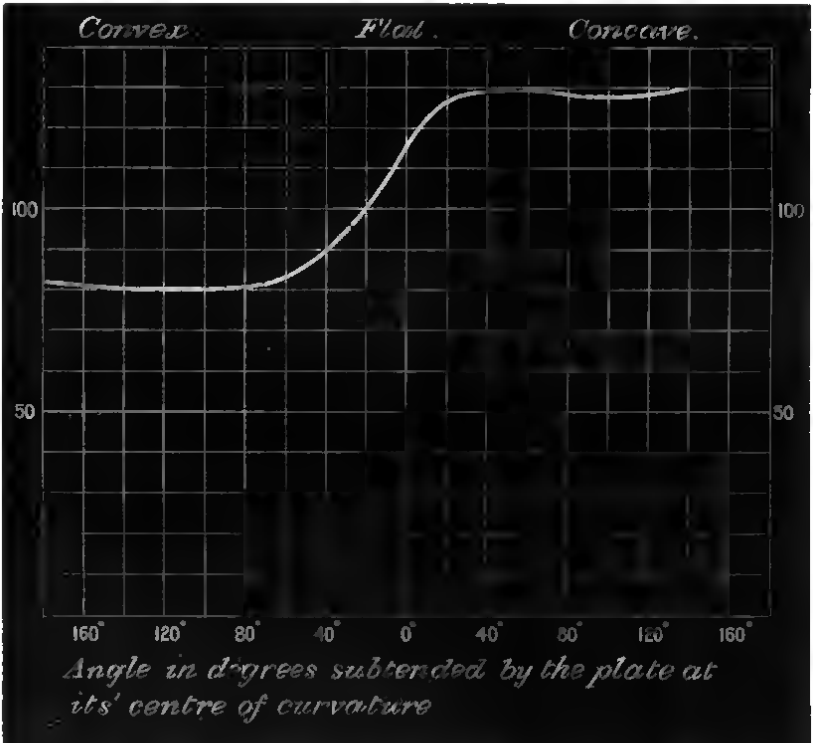


Diagram showing the Relation between the Resistance of a Curved Plate at Perpendicular Incidence per Unit Area of Projection and the Curvature.